aperture, or (3) the illumination on the subject must be increased to obtain the same exposure on the negative as when no filter is used. If any two of these are constant, the ratio of the third factor as required with the filter to the same factor without a filter is termed the *filter factor*. Thus, if the illumination on the subject and the lens aperture are constant, the filter factor is the ratio of the *times* of exposure with and without a filter, for the same effective exposure. A filter with a factor of 4 requires, under the same conditions, an increase of four times either in the time of exposure or in the lens aperture.[3]

The filter factor depends upon (1) the absorption characteristics of the filter, (2) the spectral energy distribution of the illumination on the subject, (3) the spectral sensitivity of the emulsion, and (4) processing conditions. If, for example, 75% of the total sensitivity of a blue-sensitive material lies within the blue and violet, then a color filter which absorbs the violet and blue completely, but transmits the remainder of the spectrum freely, will reduce the sensitivity to ¼ of its original value. Thus, to obtain the same effect with a filter, the exposure must be increased four times. On the other hand, if the same filter is used on a panchromatic material which has 50% of its sensitivity in the violet and blue, 25% in the green and 25% in the orange-red, the total sensitivity will be reduced to but ½ of its original value and the filter factor will be 2×.

Tungsten light contains a relatively greater abundance of long-wave radiation (yellow, orange, and red) and less violet and blue than sunlight. Consequently, a larger proportion of the total effective sensitivity will be to long-wave radiation and a smaller amount to blue and violet than with sunlight. Thus, with tungsten light, the distribution of effective sensitivity for the hypothetical panchromatic material in the preceding paragraph may be blue-violet 30%, green 20%, and orange-red 40%. A yellow filter which absorbed violet and blue only would, in this case, reduce the total sensitivity of the material to only 60% of its original value, and the filter factor would be approximately 1.6.[4]

The variation in the filter factor with the time of development and other processing conditions depends upon the gamma-wave-length characteristics of the sensitive material and is discussed in greater detail in the section which follows.

Determination of the Filter Factor. The filter factor may be computed by integration from curves representing the distribution of sensitivity with wave length with and without the filter[5] or experimentally by sensitometric methods. For example in Fig. 4.3 curve *A* is the *D* log *E* curve of a

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[3] Since practically all negative materials are subject to reciprocity law failure, the filter factor will depend upon which of the two factors—illumination or time—is increased to compensate for the absorption of the filter. In other words, the filter factor applying when the time of exposure is increased is not the same as when the lens aperture is increased. The difference, however, is small and may be ignored except in the exposure of color separation negative. See Tupper, "Filter Factors in Color Photography," *Phot.-Tech.* **2**, 29 (May 1940).

[4] With tungsten lamps, the filter factor will vary with the kind of lamp, its age, and the voltage at which it is operated. The factor is influenced at times by reflectors and diffusing materials. Filter factors vary also with variations in the spectral energy distribution of sunlight. Thus the factor of a yellow filter in the yellow light of late afternoon will tend to be less than at noon and the factor for a subject illuminated chiefly by reflected skylight will be different from one illuminated by direct sunlight. These variations, however, are seldom sufficient to be of much concern except in the exposure of three color separation negatives.

[5] Jones, *Trans. Soc. Mot. Pict. Eng.* No. 30 (1927), p. 135.

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particular emulsion exposed without a filter, whereas curve *B* represents the same emulsion exposed under the same conditions, but with a filter, both strips being developed for the same time and plotted on the same log *E* scale, the exposure values used being those produced in the sensitometer *without* a filter. It will be noted that, although both strips were developed under the same conditions, the gamma of curve A is greater than that of curve B; in other words, on this particular material, the effect of the filter used is to *lower* the gamma for a given time of development. This indicates that the gamma depends upon the spectral energy characteristics of the radiation to which the emulsion is exposed as well as on the time and conditions of development. Since the *D* log *E* curves are not parallel, it is clear that if the filter factor is determined by any of the usual methods (inertia, gradient, etc.), or from the exposures producing a given density, negatives exposed in accordance with the factor thus determined will match in density at only one point. This, however, is usually of minor importance in general photography if the densities which match are within the density range of the average negative. In determining filter factors for three-color photography, the sensitometric strips should be developed to the same gamma and the filter factors determined from the ratio of the exposures for a common density on the straight line portion of the *D* log *E* curve.

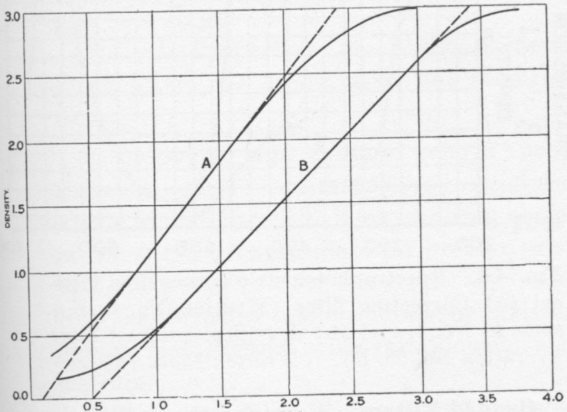

FIG. 4.3. *D* log *E* curves showing the effect of a filter on gamma. Both curves represent identical development conditions.

It will be clear from the above that the factor of a filter, on the same emulsion, when used in exposing color separation negatives, will not be the same as for black and white photography, if in this case both negatives are developed alike.[6]

In practice, filter factors may be determined quite accurately without plotting the *D* log *E* curves, simply by comparing visually the densities on the two strips and determining the ratio of the exposures for a pair of steps having the same density. The matching of the densities may be accomplished simply and readily by placing the two strips side by side on an illuminator and sliding one up and down until a step with an equivalent density is found on the other strip. The filter factor is the ratio of the exposures for the two steps.

Filter factors may be determined without a sensitometer by (1) photographing a gray scale, or preferably a step wedge, with and without a filter, but the exposure differences must be known; and (2) by making a series of exposures—preferably by varying the lens aperture so as to avoid variations in shutter speed—of a black and white photograph with and without the filter. After developing, the negatives made without a filter are compared with those exposed with the filter and images selected which have equal densities in the most important parts of the subject. The filter factor is calculated from the ratio of the two exposures.

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[6] Jones, *Photographic Sensitometry,* Eastman Kodak Co., Rochester, N. Y., 1936. Tupper, *Photo-Technique* **2**, 32 (May 1940).

Factors determined in this way will apply, of course, only to the conditions under which the original negatives were exposed and developed.

Types of Filters. Filters may be divided broadly into two classes: (1) Those which transmit the entire visible spectrum, the transmission varying with the wave length, and (2) those in which the absorption for a part of the spectrum is, for practical purposes, complete. The spectrophotometric curves of two such filters are shown in Fig. 4.4; *A* is a light yellow filter (Kl) absorbing principally between 300–500 mμ, whereas *B* is a green transmitting filter with almost total absorption except for wave lengths between 480–610 mμ. Photographic filters of the first class are frequently referred to as "correction" or, at times, as "orthochromatic" filters because they are used to obtain a more nearly correct or orthochromatic reproduction of color. To produce the desired result a filter of this type must have the absorption characteristics necessary for the particular emulsion and light source with which it is used.[7]

Filters of the second class are commonly termed "contrast" or "color separation" filters because they are used to separate, i.e., to increase the contrast between one color and others that may be present. The filter represented by curve *B,* Fig. 4.4, for example, transmits green and absorbs violet, blue, and red. It will, therefore, reproduce green objects as white, or nearly so, and violet, blue, and red objects much darker—in many many cases as black. Filters of this type find many applications in commercial and technical photography, where it is necessary to emphasize one color at the expense of others present in order to show the pattern, the structure, or to secure greater contrast between different areas of nearly the same brightness. Colors in the transmission range of a filter are reproduced light; those in the absorption range, dark.

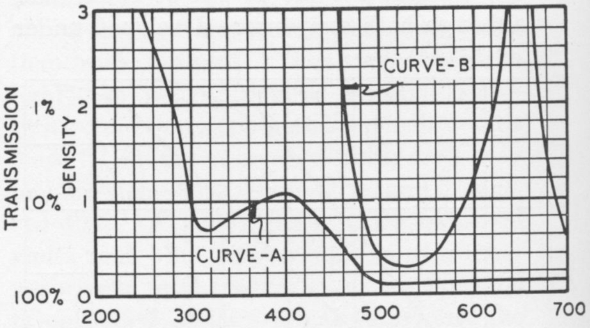

Fig. 4.4. Spectrophotometric curves of a typical (a) Correcting filter (Wratten No. 6, K_1) same as No. 1, and (b) A typical contrast filter (Wratten No. 68, B). (*Wratten Light Filters.*)

Graded Filters. A *graded* or *sky* filter is one in which the absorption increases from one side to the other. Usually in filters of this type the density of the filter dye, and therefore the factor, changes more or less uniformly from one side to the other but in some cases a filter of uniform density has been attached to a neutral wedge so that the light transmission is varied from side to side without alteration of the spectral absorption characteristics of the filter. If such a filter is placed well in front of

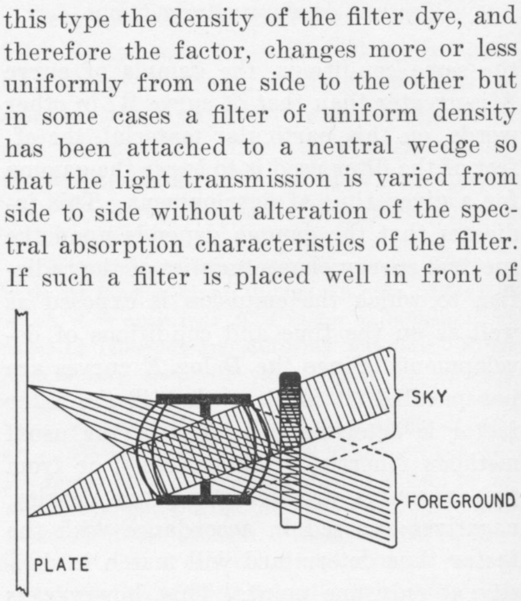

Fig. 4.5. The graded or sky filter. The effect varies with the distance between the filter and the lens.

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[7] Color compensating filters used in color photography with integral tripack materials, or with tricolor cameras, to compensate for variations in the spectral energy distribution of the light with which the picture must be made, may be regarded as a special variant of this class of filter.

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[9] Formulas for the pre
Hubl, *Die Photographisch*
Brit. J. Phot. **69**, 6 (1922)
68, 95 (1921). Gundlach
(1930). Smith, *Brit. J.*

substances described as "fog preventatives" or "stabilizers." Presumably substances of the first class tend to restrain fog in the emulsion during preparation, whereas stabilizers prevent the growth of fog in the material after coating.

Substances patented include:[9] pyrimidine, salicylamide, acetyl and diacetyl aminophenol, phenylmorpholine, pyrimidine, di- and triphenylamine, acetamides, benzamides, carbamides, thiazoles, selenomercapto-hydroxyprimidine.

There is good reason to believe that these substances find an important application in modern emulsion practice.

Additions to Paper Emulsions. Various substances, the nature of which is disclosed only by the patent literature, are added to paper emulsions, these additions being necessitated by the properties of the paper base or to prevent fog and control the color of the image. The latter will be considered here.

The addition of alkaline citrates, phosphates, borates, and chlorides is mentioned by Baker[10] for the purpose of increasing contrast and to restrain development in obtaining warm tones.

The addition of iodide, either as an alkaline iodide or as an organic compound with iodide,[11] produces green-colored images.

A comparatively large number of patents have been granted for substances which combine with free chloride ions in the emulsions to form sparingly soluble halides and thereby serve to prevent fog and, particularly, the yellow fog which appears when development is forced. These additions also assist in obtaining blue-black images.

Among the compounds mentioned in the literature are quinine, nitrobenzimidazole, benzatriazol, nitroimdazol, nitrosoquanidine, thiosemicarbazone, thioglycollic acid, 5-amidoquanide, quinone chloride, iodosobenzene, alkyl and aralkyl quinolines, and methylol nitromethane.[12]

Variable Contrast Emulsions. A number of printing papers have been placed on the market in which the exposure scale may be varied to suit the density scale of the negative by changing the color of the exposing light; e.g., *Multigrade, Varigam.* With these papers it is possible to duplicate on one paper by means of filters the range of contrast obtained on several contrast-grades of other papers.

These materials are based on one of two principles: (1) the use of two emulsions, coated separately or mixed, one of which is unsensitized; the other color sensitized and differing in contrast;[13] (2) color sensitizing with a sensitizer in which the gamma varies widely with the wave length.[14]

Experimental Emulsions. Below will be found references to publications containing formulas and directions for the preparation of emulsions. Although these may prove of value for experimental or teaching pur-

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[9] See *Photographic Abstracts* or *Chemical Abstracts* for patent literature.

[10] Baker, *Photographic Emulsion Technique,* American Photographic Publishing Co., Boston, 1941.

[11] Steigmann, *Phot. Ind.* **34**, 764, 872 (1936). *Brit. J. Phot.* **85**, 167 (1937); B. J. Almanac, p. 229 (1939).

[12] Schwartz, *Sci. et Ind. Phot.* **7**, 113 (1936). Seyewetz, *Sci. et Ind. Phot.* **6**, 300 (1935). Steigman, *Camera* (Luzern) **13**, 100 (1934).

[13] Renwick, *Phot. J.* **80**, 320 (1940). Renwick and Waller, B.P. 547,883 (1940); B.P. 541, 510–541, 515.

[14] Potter, *Photo-Technique* **2**, 59 (1940). Potter and Hagaman, U.S.P. 2,280,300.

DAVEY, KNOTT, AND EASTMAN KODAK COMPANY, U.S.P. 2,318,597.

POTTER, "Gradation Control in Photographic Emulsions," *J. Phot. Soc. Amer.* **8**, 507 (1942).

MITCHELL AND ILFORD LTD., B.P. 494,088; 547,060; 547,062.

STEVENS, B.P. 580,173 (1943) to Kodak Ltd.

CARROL, U.S.P. 2,384,598 to Eastman Kodak Company.

KODAK LTD., B.P. 552,368 (1941).

poses, it should be borne in mind that emulsion making is a highly skilled and exacting process and one must not expect to succeed at once or to produce emulsions that are of practical value. It is difficult for the amateur emulsion maker to obtain the proper raw materials, particularly a suitable gelatin, and even the resources of the average chemical laboratory are hardly adequate for the precise control necessary at every stage in the preparation of a usable emulsion. Difficulty is experienced also in coating the emulsion on paper, glass or film base—the difficulty increasing in the order named.

CARROL, "A Summary of Emulsion Knowledge," *Brit. J. Phot.* 79, 627, 1932.

CARROL, "The Preparation of Photographic Emulsions," *J. Chem. Ed.* 8, 2341, 1931.

EDER, *Handbuch der Photographie,* Vol. III, Part 1, Wilhelm Knapp, Halle a/Salle, 1930.

GREENWOOD, *British Journal Almanac 1941,* 94.

KIESER, "Emulsion Coating Device for the Laboratory," *Phot. Ind.* 30, 627, 1932.

LEROY, "Preparation of Fine-Grain Plates," *Brit. J. Phot.* 77, 125, 1930.

MIDDLETON, "Photographic Transfer Papers (Emulsions)," *Brit. J. Phot.* 75, 512, 1928.

"Preparing Unwashed Silver Chloride Emulsions," *Photo-Technique* 1, 41, 1939.

STEIGMANN, GREEN, AND BROWN, "Developing Emulsions," *Phot. Ind.* 34, 764, 1936; G. P. 505,012 silver iodide emulsion for green tones.

STEIGMANN, "Unwashed Silver Chloro Bromide Emulsions for Enlargement," *Brit. J. Phot.* 93, 140, 1946.

THORNE-BAKER, "A Homemade Chloride Emulsion," *Amer. Phot.* 37, 12, March, 1943.

THORNE-BAKER, "The Coating and Testing of Laboratory Emulsions," *Amer. Phot.* 34, 398, 400, 1940.

THORNE-BAKER, *Photographic Emulsion Technique,* American Photographic Publishing Co., Boston, 1941.

THORNE-BAKER, "Making Bromide and Chloride Papers," *Amer. Phot.* 34, 469, 1940.

WALL, *Photographic Emulsions,* American Photographic Publishing Co., Boston.

Chapter 8

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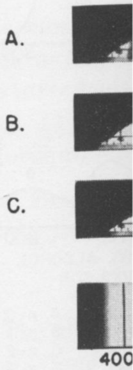
Introduction photographic e red or green, t to blue and vio violet regions H. W. Vogel certain dyes t tive approxima absorbed by t sensitizes to t green, and a b the spectrum. tivity of an en of such photog be illustrated given in Fig. sensitivity of (b) the sensi



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41; 2,186,608.

A. *Spectral Sensitivity.* By a suitable choice of dyes, emulsions can be rendered sensitive to all wave lengths from the absorption band of silver halide throughout the visible spectrum into the infrared region as far as about 13,000 Å. The general spectral distribution of sensitivity in photographic emulsions can be conveniently shown in "wedge spectrograms," examples of which are shown in Figs. 8.4 and 8.5. The manner in which these spectrograms are obtained is described elsewhere, and it need only be mentioned here that the distance of the envelope of the curve from the base at any wave length is, with certain important qualifications (*loc. cit.*), a measure of the sensitivity, on a logarithmic scale, of the emulsion at that wave length.

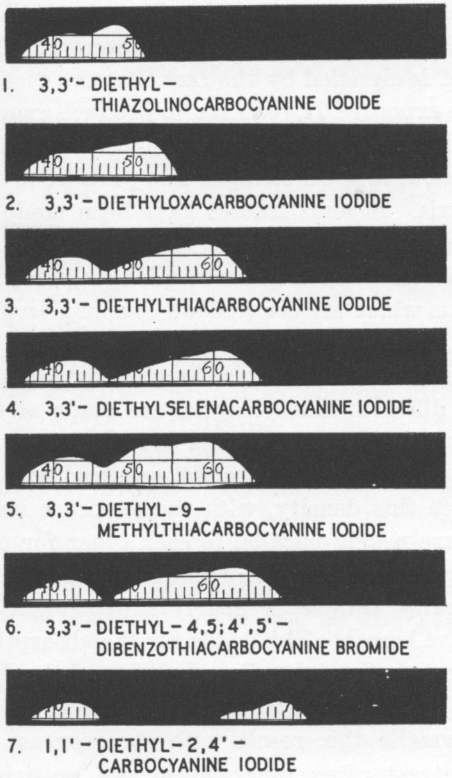


FIG. 8.4. Wedge spectrograms of a chlorobromide emulsion sensitized with carbocyanine dyes. (From Mees, *The Theory of the Photographic Process,* The Macmillan Co, New York, 1942.)

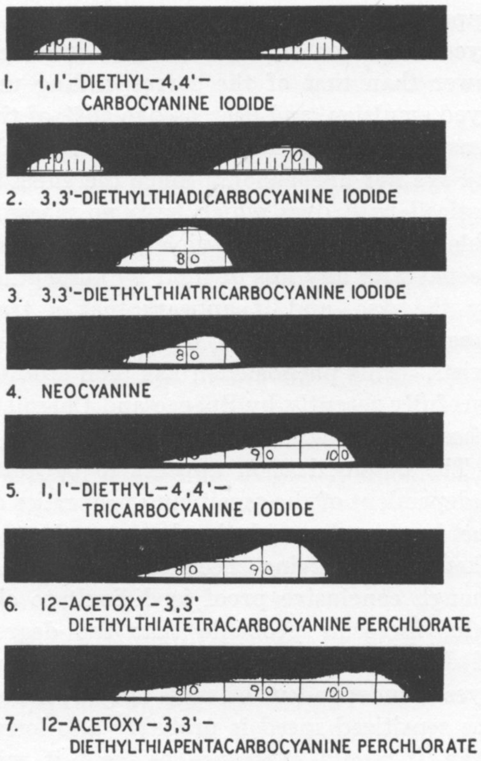


FIG. 8.5. Wedge spectrograms of a chlorobromide emulsion sensitized with infrared sensitizers. (Mees, *The Theory of the Photographic Process,* The Macmillan Co., New York, 1942.)

Sensitization over a wide spectral region is usually accomplished by adding mixtures of dyes, each sensitizing strongly at different wave lengths. It is occasionally convenient to use emulsions in which high sensitivity is restricted to a fairly narrow spectral region; e.g., emulsions with high sensitivity only in the region of the red line of the hydrogen spectrum have been useful in astronomy.

B. *Effect of Optical Sensitization on Speed.* In spite of the greater spectral range to which an optically sensitized emulsion may respond, the increase in speed to white light as compared to the speed of the same emulsion without dye is often dis-

The high moisture absorption of regular acetate compared with nitrate base means that the former will undergo a greater degree of swell when immersed in processing solutions. This behavior is undesirable in many types of professional photographic work. The high moisture absorption of regular acetate adversely affects many other physical properties as well. The acetate propionate and acetate butyrate film supports on the other hand have much greater moisture resistance and better flexibility but are about the same in strength as the regular acetate. The high acetyl acetate base is much closer to the nitrate in strength and stiffness but it does not have quite as good moisture resistance as the acetate butyrate. The permanent shrinkage of all of these types of film base may be either low or high depending on how well they are cured—that is, on the residual solvent content.

Film Emulsion Coating. Film base is coated with emulsion in rolls 36 inches or more in width and often 1000 to 2000 feet in length. The most common coating method in use involves passage of the film base beneath a roller which is immersed in a long shallow trough containing the liquid emulsion to be coated (Fig. 9.2). Suitable means of accurately controlling the temperature of the emulsion in the trough are available.

It is important that the uniformity and thickness of the applied coating be held to very rigid specifications, because emulsion thickness is very important in controlling the photographic properties of the film. Not only is it essential that the coating be of the proper thickness, but it must be uniform over both the width and the length of the roll and from one roll of base to another. Thickness is controlled by emulsion concentration, emulsion viscosity, and speed of coating.

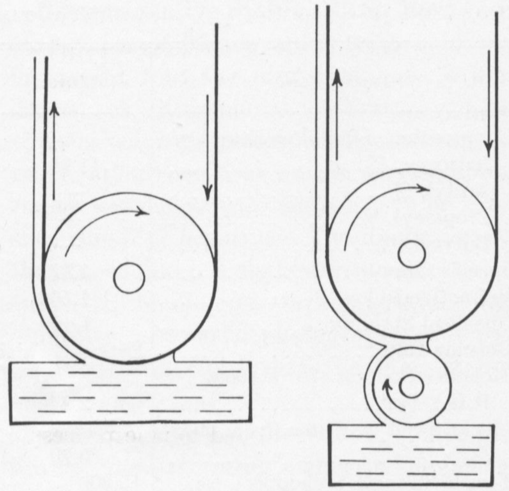


Fig. 9.2. Diagram illustrating principle of trough and roller coating machines. (Baines, *British Journal of Photography.*)

Immediately after coating, the film is chilled either by passage through a "chill box" containing refrigerated air or by contact with chilled drums. The emulsion which is normally fluid at temperatures above 90° F. sets rapidly to a gel at temperatures of 50° F. and below. Its temperature can subsequently be raised without "remelting" so that it can be dried at temperatures approximating those of normal room air.

The sheet of chilled, coated film is then conducted by automatic machinery to the drying room where it is either looped and dried in the form of festoons or carried over an arrangement of rollers continuously through the drier. The emulsion is dried by clean air of the proper temperature and relative humidity. Drying is a very important operation as lack of uniformity in drying results in a variation in sensitivity, while improper drying conditions may seriously affect the quality of the product in other ways.

Special Coatings. Film base, which has a high degree of flexibility, curls badly as the emulsion dries because of the contraction of the gelatin. This curling is counter-

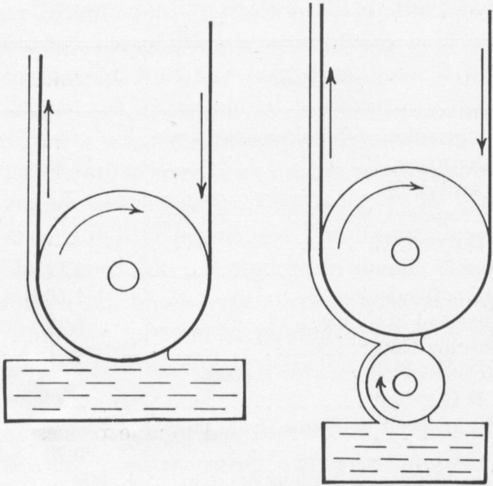


FIG. 9.2. Diagram illustrating principle of trough and roller coating machines. (Baines, *British Journal of Photography.*)

Physical Properties of the Finished Film. The physical properties of the emulsion coated film differ in several respects from those of the film base itself, notably in moisture absorption, flexibility, curl, and dimensional stability. This is because of the chemical and physical differences between the emulsion and base. The emulsion is much more susceptible to moisture than the base and expands and contracts to a larger extent with changing humidities. It is also softer and sometimes tacky when moist and more brittle than the base when very dry. Each of these factors affects the over-all properties of the film.

Moisture Relationships. Some knowledge of the various moisture relationships of photographic film is fundamental to any understanding of its physical properties. Fig. 9.3 shows how the equilibrium moisture content of different photographic materials varies with the relative humidity of the surrounding air. (It should be emphasized that it is the *relative,* not the *absolute* humidity which determines the moisture content of these and similar materials.)

Different types of film may have a gel-to-base thickness ratio as high as 1:2 or as low as 1:15 when the gelatin backing and emulsion are included together. Typical moisture equilibrium curves for several kinds of film involving different types of base and emulsion are shown in Fig. 9.4. The steep slope of these moisture equilibrium curves above 60% R.H. is noteworthy

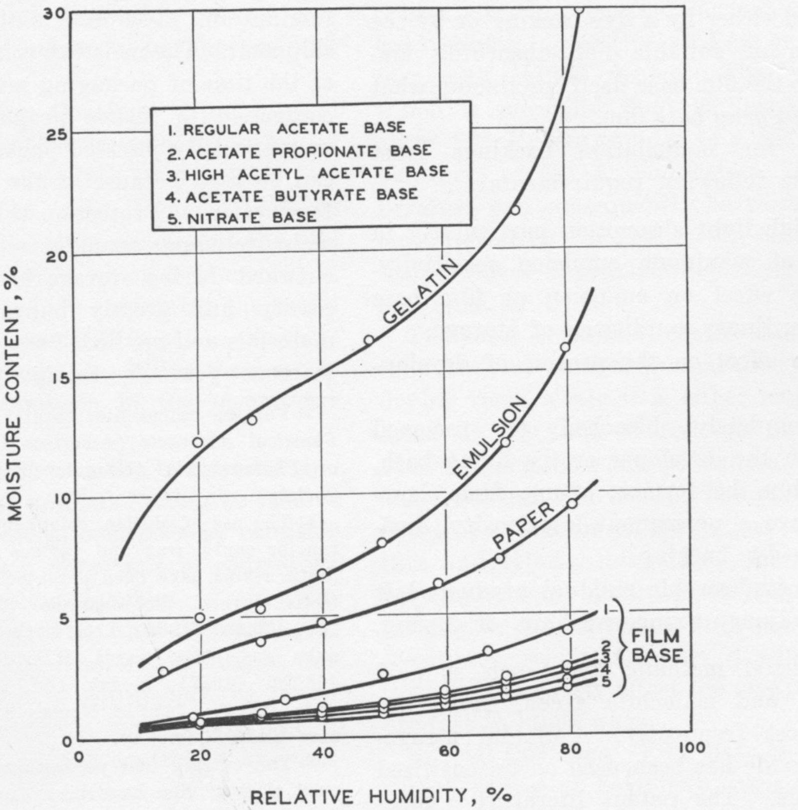
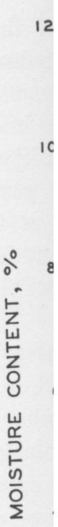


Fig. 9.3. The equilibrium moisture content of several photographic materials at various relative humidities at 70° F.



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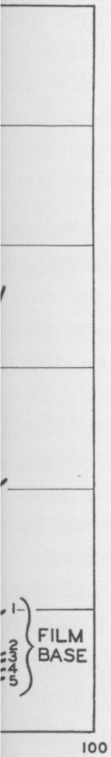

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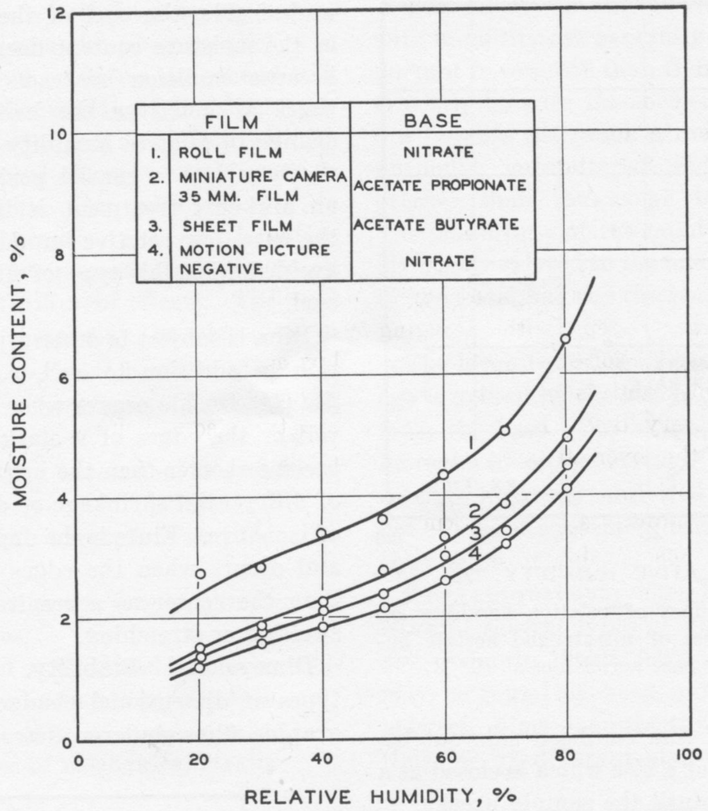

FIG. 9.4. The equilibrium moisture content of several types of photographic film at 70° F.

because it is the clue to the many adverse effects of high relative humidities on film. To eliminate the difficulties which sometimes occur in photographic work under adverse humidity conditions, many professional photographic laboratories are now using automatically controlled air-conditioning equipment.

The physical effects on the emulsion of excessive moisture include the tendency for glaze marks to appear, tackiness which may cause sticking to paper or to metal parts, the transfer of backing dyes by contact with the emulsion surface, etc. Damage from mold as well as photographic defects such as mottle, decreased sensitivity and increased fog also occur at high relative humidities. Serious damage to unprotected sensitized materials may be expected in short periods of time at relative humidities of 80% or above and in longer times at relative humidities down to 65%. It is therefore recommended that relative humidities over 60% be avoided in using or storing photographic films.

Mechanical Properties. The physical properties of film such as strength, flexibility, curl, etc., vary with the day-to-day changes in atmospheric conditions. Strength and stiffness decrease with increase in both temperature and relative humidity. Fig. 9.5 illustrates the effect of relative humidity on the brittleness of photographic film determined by placing

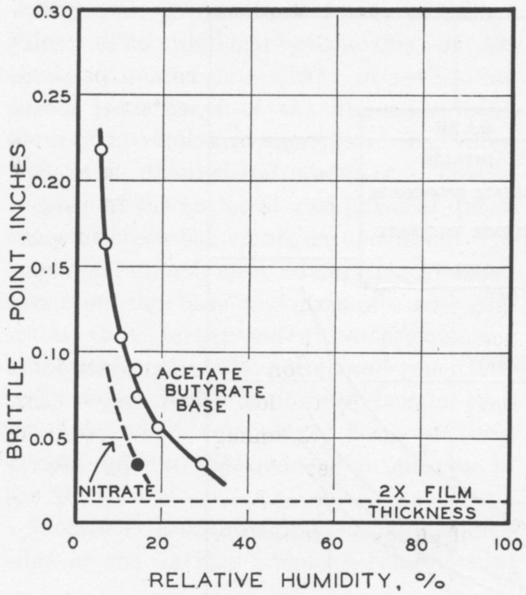

Fig. 9.5. The effect of relative humidity on the vise brittleness of nitrate and acetate butyrate safety base aerial film at 70° F.

a small loop of film emulsion side out between the jaws of a vise which is closed at a uniform speed until the sample breaks.

Above 30% R.H. film is not normally brittle, but below 20% R.H. brittleness increases rapidly. Film on safety base is generally a little more brittle than film on nitrate base but modern mixed cellulose ester and high acetyl acetate safety films are much superior in flexibility to safety films made on regular acetate base. The effect of temperature on the brittleness of film is shown in Fig. 9.6, a marked increase occurring at subzero temperatures, although even under these conditions moisture improves the flexibility as indicated in the diagram.

Deformation. The effort made in manufacture to prevent the curl of photographic film by the use of gelatin backings has already been mentioned. In the case of 35-mm. miniature camera and certain other types of film for which gelatin backings are undesirable, the curl of the film increases as the moisture content decreases. This is because emulsion contracts about 7 or 8 times as much as the base for a given change in relative humidity and thus pulls the base into a curved position. Even if an anti-curl treatment is incorporated in the base, low relative humidities should be avoided with this type of film to minimize curl.

Film is subject to other types of deformation in addition to curl, e.g., *buckle* and *flute*.[14] Buckle occurs when the edges of a roll or the edges of a stack of film sheets become shorter than the interior as a result of differential shrinkage or differential loss of moisture. Flute is the opposite of buckle and occurs when the edges become longer than the center as a result of differential swelling or stretching.

Dimensional Stability. The various types of dimensional change which photographic films undergo deserves some com-

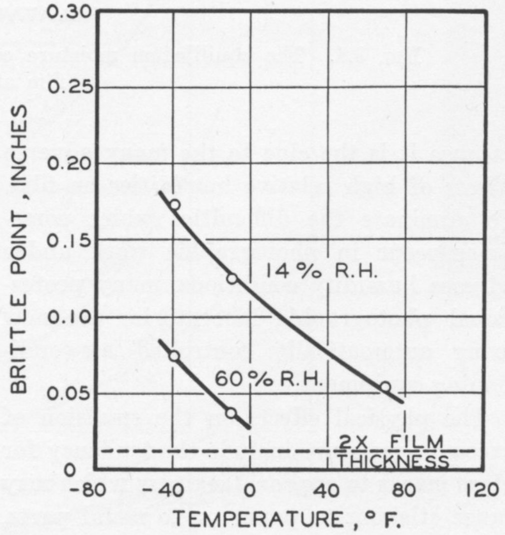

Fig. 9.6. The effect of temperature on the vise brittleness of acetate butyrate safety base aerial film.

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[14] Carver, Talbot, and Loomis, *J. Soc. Mot. Pict. Eng.* **41**, 88–93 (1943).

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B. Permanent
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2. Plastic
3. Release

TABLE 9.2. A

Base Type. . . . . .

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Gel Backing. . . . .
Gel-to-Base Thickn
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Thermal Coefficien
pansion per 1° F
Processing Shrinka
Aging Shrinkage,*
Air)
1 year at 70° F.-
1 year at 90° F.-

* Includes pro
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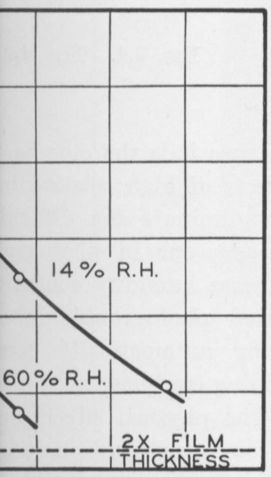

t of temperature on the
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rial film.

nd Loomis, *J. Soc. Mot. Pict.*
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ment even though shrinkage is seldom important to the amateur photographer. In some professional fields, on the other hand, the dimensional stability of the film is almost always important and often critical.

The dimensional changes which occur in any photographic film with changes in humidity, temperature, age, and handling are extremely complex and are the result of a number of different effects. The most important of these may be classified as follows:

A. Temporary or reversible dimensional changes.
    1. Humidity expansion and contraction.
    2. Thermal expansion and contraction.

B. Permanent or irreversible dimensional changes.
    1. Loss of residual solvent or volatile material other than moisture.
    2. Plastic flow.
    3. Release of mechanical strain.

The expansion and contraction of film with humidity are generally much more important in practice than thermal expansion, not only because the coefficients are larger but because the range of relative humidity normally encountered indoors is much greater than the range in temperature. The magnitude of the humidity coefficients is directly related to the moisture resistance of the base and the thickness of the emulsion.

The largest portion of permanent shrinkage is caused by the loss of residual solvent from the base. Shrinkage is increased by increase in either storage temperature or relative humidity and is decreased by the use of closed containers which prevent free circulation of air.

The approximate shrinkage characteristics of several types of photographic film are given in Table 9.2. Some variation may be found between individual films or between films manufactured at different times or by different manufacturers. The

TABLE 9.2. APPROXIMATE SHRINKAGE PROPERTIES OF VARIOUS TYPES OF PHOTOGRAPHIC FILM

	Roll Film Film Pack	Motion Picture 35-mm. Neg. Film	Reversal 16-mm. Film	Miniature Camera 35-mm. Film	Topographic Aerial Film	Sheet Film
Base Type	Nitrate	Nitrate	Regular acetate	Acetate propionate	Acetate butyrate	Acetate butyrate
Base Thickness, Inches	0.0033	0.0053	0.0053	0.0053	0.0053	0.0082
Gel Backing	Yes	No	No	No	No	Yes
Gel-to-Base Thickness Ratio	1:2.5	1:6	1:8	1:6	1:7	1:5
Moisture Content at 70° F.—50% R.H.,	4.1	2:3	3.8	2.8	2.4	2.8
Humidity Coefficient of Linear Expansion per 1° F.$\times 10^5$	11	6.0	11	9.5	8.2	8.0
Thermal Coefficient of Linear Expansion per 1° F.$\times 10^5$	—	3.0	4.7	4.1	4.3	4.0
Processing Shrinkage, %	0.20	0.12	0.20	0.10	0.04	0.10
Aging Shrinkage,* % (Open to the Air)						
1 year at 70° F.—50% R.H.	0.40	0.50	—	0.40	0.09	0.15
1 year at 90° F.—90% R.H.	1.2	0.75	—	0.75	0.05	0.75

* Includes processing shrinkage.

Note. Where precise engineering data are required on current film products, the manufacturer should be consulted.

bromide, formed by precipitation in water, and the reduced silver is collected and measured. The reduction potential of the developing agent is then expressed in terms of the quantity of metallic silver produced from the reduction of the silver bromide.[27]

3. *Electrometric methods.* Electrometric methods have been utilized by Bredig, Matthews and Barmeier, Frary and Nietz, and more recently by Evans and Hanson.[28] The results obtained by the latter are quite different from earlier measurements made by the density depression method as will be evident from the following table in which the values from the density depression method, used by Nietz, are compared with those obtained by the electrometric method; the potentials given being measured against the standard saturated calomel reference cell.

	Reduction Potential	
Developing Agent	*Density Depression Method*	*Electrometric Method*
Diaminophenol	30	−0.434
Bromhydroquinone	21	−0.327
Monomethylparaminophenol sulfate	20	−0.308
Pyrogallol	16	−0.388
Dimethylparaminophenol sulfate	10	−0.293
Chlorhydroquinone	7.0	−0.335
Paraminophenol (HCl)	6.0	−0.291
Toluhydroquinone	2.2	−0.390
Hydroquinone	1.0 (standard)	−0.357
Paraphenylene diamine	0.3	—

The outstanding difference in the values obtained by the two methods is the much higher potential of hydroquinone with the electrometric method than with the older density depression method. It will be observed that the potential of hydroquinone, as measured by the electrometric method, is higher than that of monomethyl-paraminophenol (metol), while the difference in potential is greater, and in the opposite direction, when measured by the depression of density. The potentials, as measured electrometrically, do not correspond very well with the observed differences in the rate of development, or velocity constant, but are in fair agreement with the maximum densities obtainable with the various developing agents.

Differences in Developing Agents With Respect to Rate of Exhaustion. With all developers, there is a loss in activity with use. This loss in activity affects development in two ways: (1) longer development is required to reach a given degree of contrast or gamma, and (2) the lower densities are less fully developed tending to produce the effect of underexposure.

The effect of repeated use on density with different developing agents using a standard formula was investigated by Strauss who found that metol has the longest useful life, followed in order by paraminophenol, edinol, ortol, chloro-hydroquinone, glycin, pyrocatechin and, much worse than the others, pyro.

Ermen investigated the exhaustion of developers using the time of appearance on developing papers.[29] His results placed the different developing agents in the following order: metol (best), dimethylaminophenol, paraminophenol, metol-chlorohydroquinone, chloro-hydroquinone, and lastly hydroquinone.

Identification of the Principal Developing Agents. Methods of identifying the various organic developing agents have been described by Andresen,[30] Clarke,[31] Er-

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[27] Andresen, *Phot. Korr.* **35**, 447 (1898). Valenta, *Photographische Chemie und Chemikalien-Kunde*, II, 506, Wm. Knapp, Halle a/S.

[28] Evans and Hanson, *J. Phys. Chem.* **41**, 509 (1937).

[29] *Brit. J. Phot.* **68**, 64 (1921).

[30] Andresen, Valenta, *Photographische Chemie und Chemikalienkunde*, Knapp, Halle a/S.

[31] Clarke, *J. Ind. and Eng. Chem.*, November, 1918; *Brit. J. Phot.* **65**, 499 (1918).

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tandards was adopted.

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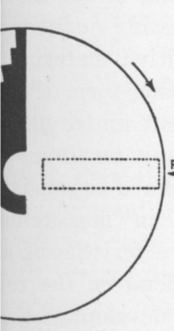

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L represents the standard lamp which is the source of illumination. A selectively absorbing filter, *F*, is placed in the path of the light coming from the lamp in order to modify its spectral composition to the desired quality. A plane mirror, *M*, reflects the light at right angles, thus illuminating the exposure plane, *EP*, in which the photographic material is placed. The rotating cylindrical shutter or drum, *D*, having 21 exposure slots of increasing length controls the time of exposure upon adjacent steps of the sensitive material. The platen, *PL*, when pulled down, serves to hold the film strips in the exposure plane during exposure.

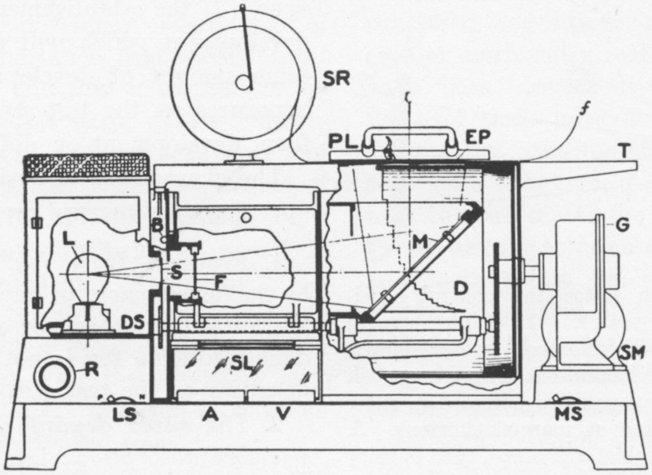

FIG. 17.2. Optical system of the Eastman IIb sensitometer (time-scale).

The drum is driven at a constant angular velocity by a synchronous motor, *SM*. Through a reduction gear, *G*, the motor turns the drum at 12 r.p.m. when operating on a 60 cycle line, or at 10 r.p.m. on a 50 cycle line.

When the machine is started by throwing the master switch *MS*, the drum revolves continuously. Exposures are made by means of the shutter, *S*, operated by a one-turn mechanism. Upon pressure of the release button, *B*, this shutter opens while the photographic material is protected from the exposing radiation by the opaque portion of the drum, and closes as soon as the slots in the drum have passed the exposing plane.

Illumination Scale Sensitometers. The illumination on different parts of the sensitive material may be varied to produce an illumination scale of exposures by (1) varying the distance between the light source and the sensitive material for the different exposures, (2) by the use of tubes, or cells, with apertures of various sizes in one end, the sensitive material being placed at the other,[1] (3) by optical wedge methods, consisting of a stepped diagram and a cylindrical, deforming lens,[2] (4) by placing a series of densities[3] in front of the sensitive material so that the illumination is varied in accordance with the transmission

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[1] See Eder, *Handbuch der Photographie.*

[2] Callier, *Phot. J.* **43**, 242 (1913); *Brit. J. Phot.* **60**, 972 (1913). McFarlane, *J. Franklin Inst.* **228**, 445 (1939).

[3] The density scales used in such instruments are made of pigmented gelatin according to a method devised by Goldberg (*Brit. J. Phot.* **57**, 642, 648 (1910)), or are calibrated photographic copies of such wedges.

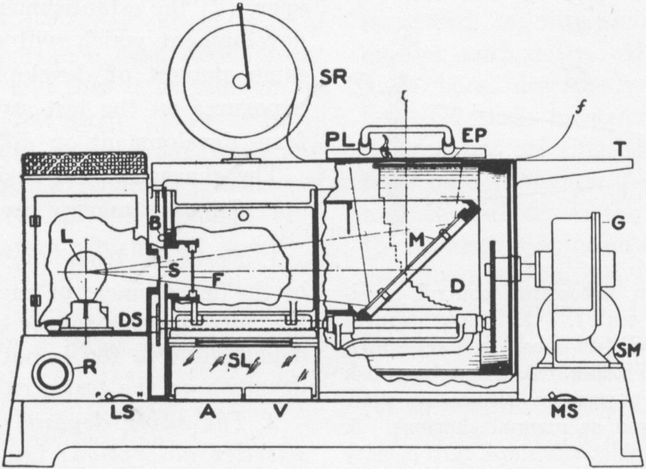

FIG. 17.2. Optical system of the Eastman IIb sensitometer (time-scale).

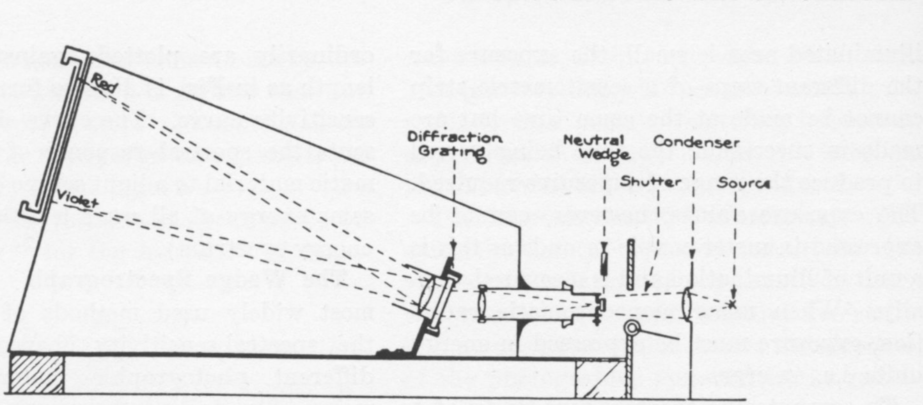

Fig. 17.12. Optical system of the wedge spectrograph.

this region and if wedge spectrograms are used simply for comparing different materials.

Filter Methods. Sensitometric exposures made through suitable filters, rather than in the monchromatic sensitometer, provide a simple and useful means of determining spectral sensitivity although the results cannot be compared from the standpoint of completeness or accuracy. The difficulty lies in the fact that the filters available do not permit of the isolation of different parts of the spectrum equally or without overlapping. While a division of the spectrum into 5 or 6 nonoverlapping parts is possible with combinations of existing filters, in general this method has been confined to the red, green, and blue-violet filters used in three-color photography. Results of practical value may be obtained by making sensitometer test strips with each of the filters, developing to (1) the same gamma or (2) for the same time, depending upon the requirements, and determining the relative sensitivity by the exposure difference for (1) visually matched densities or from (2) D log E curves using (a) inertia speeds, (b) the exposure for a given density, or (c) fractional gradient values.

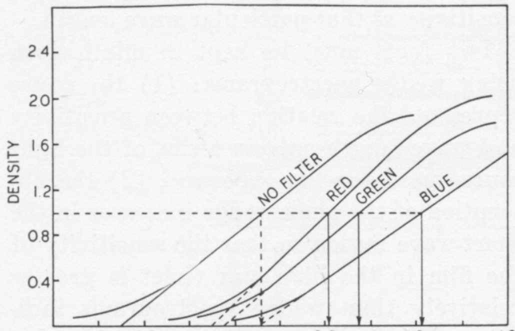

Fig. 17.13. D log E curves of a panchromatic emulsion showing the results of exposures through a typical set of three-color filters. (Wratten ABC$_4$.)

Variation of Gamma with Wave Length. Although the three sensitometric strips shown in Fig. 17.13 were developed together for the same time, the gammas are not the same. Gamma depends upon the spectral characteristics of the radiation to which the material is exposed as well as on the emulsion and conditions of development. Thus, with uniform development, the values for spectral sensitivity and the filter factor depend on the density chosen as a basis of comparison; if, however, the three strips are developed separately to the same gamma, the values are independent of the density.

Throughout the range of sensitivity of silver bromide in gelatin the variation in gamma with wave length is very nearly in-

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[22] Davey, *Phot. J.* 8

[23] Method of Deter
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become $A = 1{\cdot}33$, $B = 1{\cdot}73$. The opacities (antilog of the densities) are now 20 and 54 respectively, and the ratio of the printing exposures becomes 1:2·7.

Measurement of the Callier factor in this way also allows for light flare in the enlarger lens.

Silver

Densitometers measure diffuse density because this is easily standardized. Specular density measurements depend on the precise layout of the measuring instrument used, and are therefore less specific.

DYE

All this applies to silver images (for example, of separation negatives or masks). Dye images, as in a colour transparency or colour negative, scatter the light far less. Accordingly the Callier factor is very much lower and may often be ignored altogether.

With separation or colour negatives and transparencies we are mostly concerned with transmission density. Print densities are measured by reflected light, yielding reflection densities. These again can be specular or diffuse. However, as we can judge colour print quality visually, this aspect of densitometry rarely enters into practical colour photography.

Densitometers

Transmission densitometers are of two main types, visual and photo-electric.

The former usually have a single source of illumination and split the light into two separate beams. These are later brought together so that their intensity can be compared by viewing through the eyepiece of the instrument.

In the simplest form of visual densitometer one beam passes through the unknown density and the other through an adjustable calibrated wedge. In use the wedge is moved until the two fields appear to be of the same intensity. The density can then be read off the scale which is attached or linked to the wedge. This system has the disadvantage that the comparison between the two

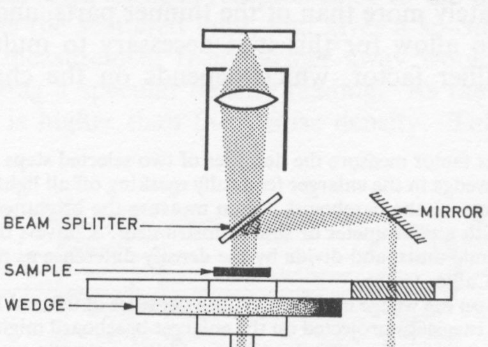

Fig. 80 Capstaff-Purdy densitometer. The unknown density is balanced against a constant one with a calibrated wedge via a beam splitting and mirror system, and the two compared in an eyepiece.

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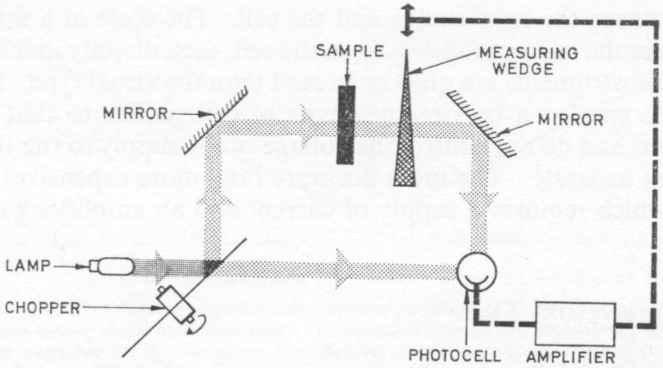

Fig. 81 Automatic densitometer. A photo-cell compares the measuring beam (going through the sample and a measuring wedge) with a direct reference beam, the two being separated by a chopper which alternately reflects light along the measuring path and transmits it directly to the photo-cell. When the density of the sample changes, an A.C. current is generated, and this—via an amplifier system—moves the measuring wedge to restore the balance so that the intensity of both light pulses from the two paths are equal on the photo-cell. The wedge movement is linked with a suitable recording system.

fields has to be made at different levels of illumination depending on the density being measured, and cannot always be at the level where a match can best be made. Constant-density densitometers overcome this difficulty by keeping one field at a constant level of illumination and putting both the wedge and unknown density in the other beam of light. Thus when the two fields are balanced the sum of the unknown density and that of adjustable wedge will always be constant, and the intensity of the light transmitted equal to that of the reference field.

For example, suppose that initially the two fields are balanced when the wedge has a density of 3·0 and that a density of say 2·0 is to be measured. The wedge then requires moving until its density is 1·0; when the sum of the two densities will again be 3·0 (Fig. 80).

The accuracy of a visual densitometer depends primarily on the observer and the calibration of the wedge. With a well-designed instrument the fields can usually be matched within a density of plus or minus 0·02. An easy way of testing the absolute accuracy of the instrument is to get a step-wedge measured by the makers and then to take several readings on it. Where the average reading for density differs from the maker's figure, the discrepancy should be noted. The instrument error can then be plotted against measured density in the form of a graph and used to correct subsequent readings.

Most densitometers are intended to give readings of the diffuse and not the specular density (see page 286) but this is not always completely realized in practice. Any error which increases proportionately with density, so that it can be plotted as a straight line on the error graph, is due to this cause. For most purposes errors of this nature can be ignored.

In the photo-electric type of densitometer the density to be measured is interposed between the light source and the cell. The scale of a milliammeter, which measures the current flowing from the cell, then directly indicates density values. These instruments are quicker to read than the visual type. But cheaper models (which employ a barrier-layer type of cell similar to that used in an exposure meter, and do not control the voltage of the supply to the light source) tend to be less accurate. The more accurate (and more expensive) types use a vacuum cell which requires a supply of current and an amplifying circuit.

Plotting a Characteristic Curve

In a sensitometric laboratory characteristic curves are frequently plotted by automatic recording densitometers. These measure the density along a continuous wedge exposed on the negative material, and directly record the density readings on a chart against exposure levels. We can, however, plot a curve fairly easily from a step-wedge exposed on the film or plate, by measuring the different step densities with a normal densitometer.

Only part of the characteristic curve (page 109) is a straight line. There the density is directly proportional to the logarithm of the exposure. However, the density an emulsion can produce is limited. When the amount of exposure reaches this saturation point, the density ceases to be proportional to the logarithm of the exposure, and the upper end or shoulder of the curve flattens out. There is also a certain minimum exposure which is required to produce any image at all. The density-log exposure relationship does not apply in the neighbourhood of this minimum exposure, either. The lower end or toe of the curve also flattens out. Moreover, the curve does not even start at the zero density level, but nearly always a little higher up. This is due to an initial density—the fog level—produced by the emulsion even without exposure.

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& min
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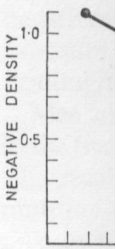
Gamma measurements must therefore always be taken from the straight-line portion of the curve. In other words, the overall gamma as measured by comparing two separate densities on the grey scale, must be the same as the gamma obtained by comparing each of these densities with the adjacent one.

If the negative has been exposed under a wedge, all we need to do in order to plot the graph is to measure the densities of each step of the wedge and those of the corresponding steps in the negative. These might be as follows:

Step-wedge . .	2·0	1·4	0·8	0·2
Negative . .	0·2	0·5	0·8	1·1

Now the actual exposure that the material receives is least when the density of the step-wedge is greatest. If the figures are plotted as they stand, the smallest step-wedge density would have to appear at the right hand away from the origin of the graph. This may easily be corrected by subtracting each of the wedge



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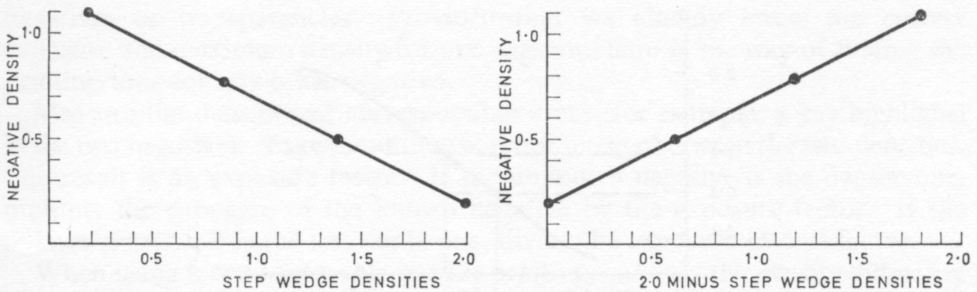

Fig. 82 Plotting negative densities against the step wedge densities gives an approximate characteristic curve, but of the wrong slope direction (*left*). To obtain a density/log exposure plot, the densities are plotted against negative wedge densities (i.e. density steps subtracted from a constant equal to at least the maximum density (*right*). This also gives a value for the gamma—here 0·5.

densities from a figure equal to or greater than its maximum density. In this instance 2 is chosen (Fig. 82). The step-wedge and negative densities become:

Step	(1)	(2)	(3)	(4)
Step-wedge . .	0·0	0·6	1·2	1·8
Negative . .	0·2	0·5	0·8	1·1

Once the curve is plotted we can then measure the gamma value (page 284). To clarify this item of terminology, gamma is a measure of the relative contrast of a negative as compared with the subject over the straight-line portion of the characteristic curve. When we talk of contrast we must, however, distinguish between average contrast—which is a ratio of density differences—and the contrast between two brightnesses which is the difference between their densities in a negative. The average contrast, loosely also referred to as gradation, is something similar to gamma, but without being confined to the straight-line part of the characteristic curve.

Since densities are logarithmic, a density difference corresponds to a brightness range. Thus a density difference of 0·6 is a brightness range (more precisely, opacity range) of 4:1. The maximum brightness range of a negative is the antilog of its density range (i.e. the difference between the maximum and minimum densities). So if the measured highest and lowest densities of a negative are 0·3 and 2·7 respectively, the density range or difference is 2·3. This corresponds to a negative brightness range of 1:200. Part of this density range at either end will probably include the toe and shoulder of the characteristic curve. The density range for correct reproduction (over the straight-line portion only) might be from 0·5 to 2·4, or 1·9. This corresponds to a negative brightness range of about 80:1.

Density Measurement in Practice

The need for working out exposure changes based on density measurements arises, for example, when a trial separation negative (or mask—page 316) proves

Trial exposure

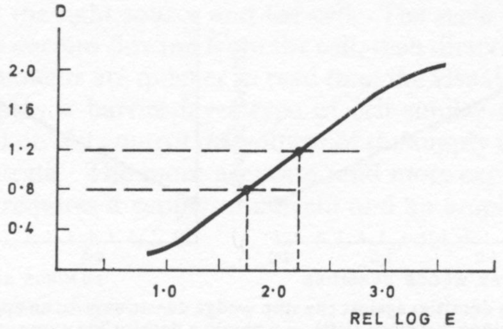

Fig. 83 Exposure corrections. The most straightforward way of using a characteristic curve is to establish the exposure increase (or decrease) required to obtain a specific density change. This simply involves establishing the actual and required density points on the curve (e.g. 0·8 and 1·2) and finding the relative log exposure difference—here 0·5. The antilog of that gives the exposure factor required.

to be under- or over-exposed. Equally we may need such measurements in order to establish required filter factor corrections when a set of separation negatives is out of balance.

To take a concrete example let us suppose that a certain area in a trial negative has a density of 0·8 and that we wish to increase this to 1·2 in a subsequent negative. If the characteristic curve of the negative, or one developed to a similar gamma is available, we only have to mark the points on the curve corresponding to the two densities and drop perpendiculars from them on to the log exposure axis of the graph. The distance between the perpendiculars measured on this axis then gives the change in log exposure needed to produce the required alteration in density. This might be, perhaps, 0·5. To turn this into an exposure factor, take the anti-logarithm (see table on page 400), in this case 3·15. If the density is to be increased (as in our example), multiply the original exposure by this factor. Thus if the exposure was 12 seconds, the new exposure will be 12 × 3·15 = 37½ seconds. If the density is to be reduced, divide the original exposure by the exposure factor (Fig. 83).

In the method described measurements were made directly on the graph. But if the curve is a straight line over the densities in which we are interested and the gamma is known, the required change in log exposure is simply the difference between the two densities divided by the gamma value.

For separation negatives and most masks the correct exposure is one which will give a certain minimum density in the negative. Where the negative is under exposed this density is likely to fall too near the toe of the characteristic curve. Consequently calculations based on the gamma of the straight-line portion of the curve will not give correct results and it is wisest to measure the differences in log exposure direct from the characteristic curve. Another factor which may upset the calculations when exposure times run into more than a few seconds is reciprocity failure (page 116).

Density measurements are also used in determining printing exposures for

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layers sensitive not to the red, green and blue thirds of the visible spectrum, but to considerably narrower and more widely spaced bands. For example, the cyan-forming layer may be sensitive to a narrow band covering far red and near infra-red instead of yellow to red. Similarly, the magenta-forming layer may cover only a narrow green band, and the yellow-forming layer a limited blue-violet band (Fig. 47).

This system would not be possible with either a colour negative film or a reversal film used for original photography. These materials have to analyze the colours of the original subject and thus must cover the whole visible spectrum

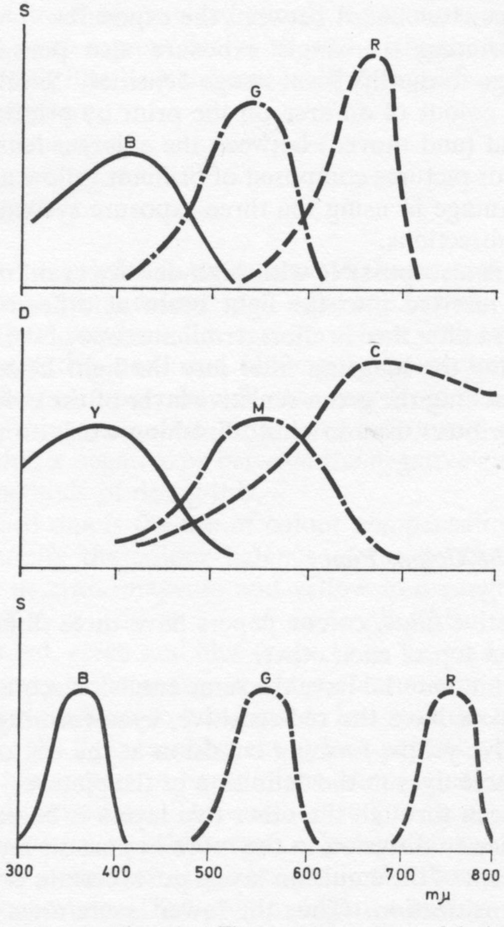

Fig. 47 Keying of colour negatives and papers. The sensitivity curves of the layers in a colour negative film (*top*) normally overlap appreciably. The absorption characteristics of the yellow, magenta and cyan dyes formed in those layers (*centre*) overlap even more, so that accurate separation in positive printing becomes difficult. One possibility is to use a positive paper with widely separated sensitivities to regions of the dye absorption where the overlap with the other dye curves is at a minimum. The bottom diagram shows a hypothetical set of such sensitivity curves.

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Tri-colour printing normally uses narrow-cut filters, and this method is more selective in its effect on the three emulsion layers. In theory at least, it is potentially capable of giving greater colour saturation in the finished print than single-exposure white-light printing. In practice the losses in saturation that should occur with white-light printing are avoided due to the narrow sensitivity bands of the print material. This achieves the same object as the narrow transmission bands of the primary filters for tri-colour printing. Using a single exposure also eliminates one of the major problems of earlier forms of photographic colour printing: the three dye images are exposed simultaneously, and necessarily remain in register. There is no risk of accidentally displacing the paper on the enlarger baseboard between the exposures.

In white-light printing the single exposure also permits straightforward shading of the image to modify local image densities. Similarly, it is relatively easy to change the colour of an area on the print by printing part of the time through a filter held (and moved) between the enlarger lens and the projected image. However, for pictures composed of brilliant yellow and blue tones there is some slight advantage in using the three-exposure system despite its lack of flexibility in other directions.

Colour printing is also possible with high-density cyan, magenta and yellow filters if these are inserted into the light beam at different times during the exposure. Inserting a filter then in effect terminates one of the additive exposures. For example, putting the magenta filter into the light beam stops any further green light from reaching the green-sensitive layer of the colour paper. Certain automatic colour printers used in photo-finishing work on this principle (page 188).

Characteristics of the Colour Paper

Like colour negative films, colour papers have three differentially sensitized emulsions coated on top of each other.

Some types of print material have the same emulsion sequence as the negative film, but other papers have the red-sensitive, cyan-forming emulsion on top, and the blue-sensitive yellow-forming emulsion at the bottom. Yellow contributes least of the three dyes to the definition of the picture; the slight diffusion of the yellow dye seen through the other two layers is barely detectable and is preferable in practice to diffusion in the more important layers.

Such rearrangement of the emulsion layers poses certain problems of ensuring truly differential sensitization. Thus the lower layers must not be sensitive to light to which the top layer is sensitized, but a yellow filter layer cannot be used once the blue-sensitive layer is no longer on top of the tri-pack.

The sensitivity of the positive paper layers does not necessarily correspond to the sensitivity of the negative emulsions. Thus some positive papers have their

Data sheets issued by manufacturers indicate the materials most suitable for colour-separation work. Special emulsions are available which give approximately equal contrast in all three separation negatives with similar development times (page 256).

Tri-colour filters in their cheapest form are thin sheets of dyed gelatine for mounting in front of or behind the lens. Care must be taken, however, not to damage the surface of the filters, and they are best mounted by the edges in a cardboard cut-out holder. Glass-mounted filters must be optically flat, otherwise the three images—although of the same size—may suffer from local distortions leading to coloured fringes in the finished picture. Such filters are expensive and must receive the same care as the lens itself. With lenses of focal lengths less than 10 inches it is normally permissible to use filters cemented between selected parallel plate glass, which is considerably cheaper than optically worked "flats".

Although the order in which the exposures are made is immaterial, it is convenient to mount the filters so that the first exposure is made through the red filter, the second through the green, and the last (which in tungsten light is the longest) through the blue. Focusing can then take place through the red filter, which gives a bright image on the focusing screen. Arranging that the last exposure is the longest will often save the day when a still-life group includes material such as flowers which may start wilting during a series of prolonged exposures. As the blue-filter negative is eventually printed in yellow, any lack of register due to movement is then less obvious.

From the point of view of analyzing the light from an object into its red, green and blue components (page 31) not only the transmission of the filters chosen (approximately one-third of the spectrum for each—page 244) are important, but also the effect of the filters on the negative material. Transmission curves obtained by measuring the actual percentage of the light transmitted by a filter at each point in the spectrum, take no account of what happens to this light after it has passed through the filter. Since this light is recorded on a photographic emulsion, and it is the nature of this record which determines the colours obtained, some convenient method of determining the photographically effective transmission is necessary.

This can be done with a wedge spectograph, consisting of an upright illuminated slit, the light from which is split up into a spectrum by means of a prism. In front of the slit is placed a neutral grey-wedge. The intensity of the light from the slit thus gradually decreases along its length, with all the light falling on the slit passing through it at one end and only 1/10,000 of the incident light being transmitted at the other.

The resulting spectrum (really a series of overlapping images of the slit) is therefore graduated in its intensity. When it falls on a photographic emulsion, the height at each point of the recorded spectrum is a measure of the sensitivity of the emulsion to light of that particular wavelength. The resulting negative therefore traces out graphically the sensitivity curve of the emulsion, and such photographs are called wedge spectograms (page 235). Similar spectrograms made through the tri-colour filters show the response of the emulsion to the light transmitted by each filter (Fig. 64).

In theory the curves obtained in this way should match the mixture curves of the coloured lights used for reproducing the colours in additive synthesis (page 326) or the absorption curves of the dyes in subtractive synthesis (page 304). In practice we can never achieve this—mainly owing to the shortcomings of the dyes—and the compromise aimed at is to have filters which yield a set of reasonably separate wavelength-sensitivity curves with a certain amount of overlap (page 244). The deficiencies of the dyes in subtractive synthesis are then usually compensated by separate controls such as masking (page 296).

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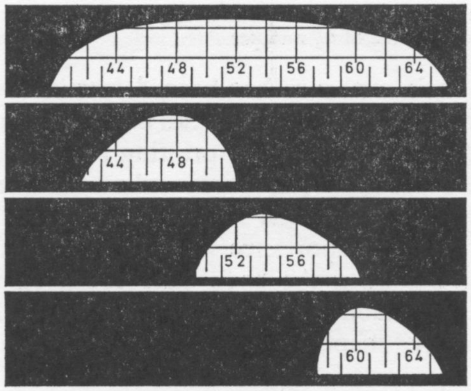

Fig. 64 Wedge spectrograms of a typical panchromatic emulsion by daylight (*top*) and of the same emulsion exposed through typical tri-colour blue, green and red filters respectively.

The film manufacturers' recommendations of separation filters for their products are based on tests of this kind which, however, are beyond the scope of the photographer. In practice the tri-colour separation filters sold by reputable manufacturers are found to be very much alike. While it is obviously best to use a separation filter set recommended for the negative material to be employed, in practice most filter sets can be used for any particular brand of film or plate.

Filter Factors

In daylight, typical factors for the tri-colour filters are of the order of about 7–8 times normal for the red, 9–10 times for the green, and 10–15 times for the blue filter, with a normal panchromatic material. In tungsten light the relative preponderance of red leads to factors of approximately 3–5 times for the red, 9–10 times for the green, and 12–20 times for the blue filter respectively. In either case the actual filter factor depends on the emulsion, the make of the filter, and even on the degree of development. Variations of the latter may call for appropriate correction in published filter factors (page 257).

At long exposures reciprocity failure (page 116) can substantially alter the filter factors from those which would yield balanced negatives made with shorter exposures. If we compensate for the filter factor by adjusting the camera lens stop, the exposure times can be the same. The effect of reciprocity failure is then identical for all the negatives and the exposure times do not affect the filter factors.

For this reason British Standard No. 1437:1948 recommends quoting filter factors both for intensity and for time correction (the latter being based on a no-filter exposure of 10 seconds). For example, one manufacturer adopting this system gives intensity (*I*) factors for artificial light with a given emulsion of 2, 8, 20 (red, green, blue), while the corresponding time (*T*) factors are 2¼, 11 and 40. According to these *T* factors, based on an unfiltered exposure of 10 seconds, the filter exposures would be 22½,

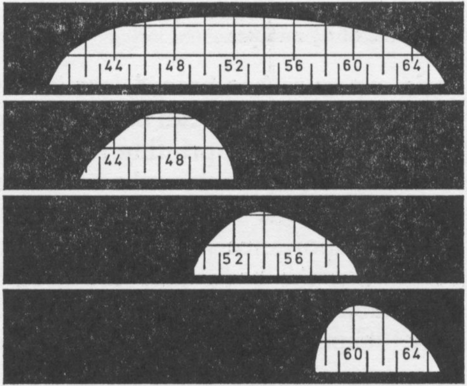

Fig. 64 Wedge spectrograms of a typical panchromatic emulsion by daylight (*top*) and of the same emulsion exposed through typical tri-colour blue, green and red filters respectively.

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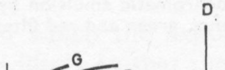

110 and 400 seconds respectively. So at an exposure time of $\frac{1}{3}$ minute the emulsion is almost twice as fast as it is with an exposure time of $6\frac{1}{2}$ minutes.

Provided that the basic exposure has been determined with reasonable accuracy, quite large errors in the factors used can be compensated for by increasing or decreasing the exposures given when printing from the negatives. Indeed, without this latitude separation sets could only be made successfully under rigidly controlled lighting conditions in studios with artificial light. Highly accurate factors are only of importance when photographing very long range subjects, or on occasions when the basic exposure used verges on under or overexposure. Unsuitable factors may then place some of the tones of the three negatives on differently shaped portions of the emulsion characteristic curve (Fig. 65).

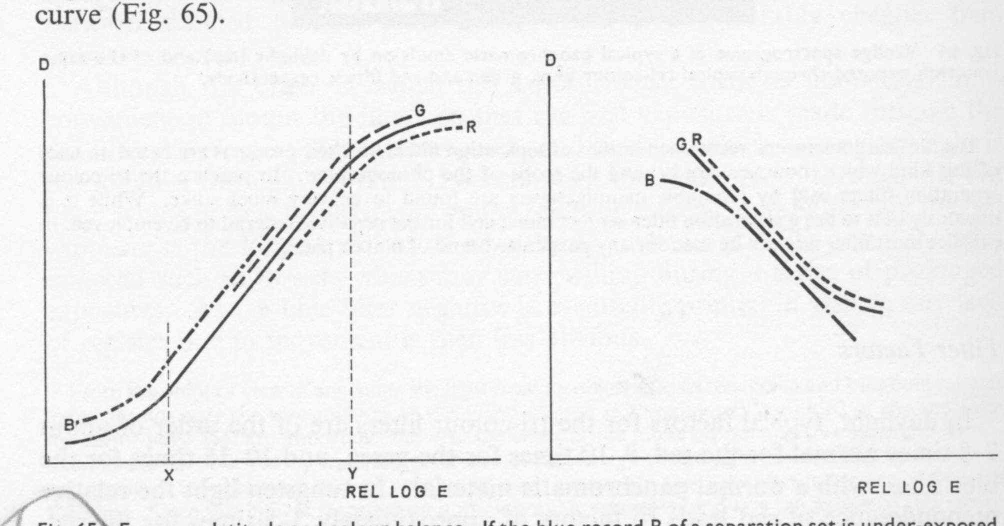

Fig. 65 Exposure latitude and colour balance. If the blue record B of a separation set is under-exposed and the green and red records G and R over-exposed, only densities between the points X and Y lie on the straight line-portion of the characteristic curve (*left*) of the material. When printed (*right*), the characteristics of such a set do not match—hence no good grey scale is obtainable at all densities and the colour reproduction will suffer.

Grey or Black Printers

Sometimes a fourth negative is made through a yellow or light green filter and used to print a grey "key" image which acts as a neutral foundation for the colour print. Theoretically, this fourth grey printing is unnecessary, and it is rarely used by colour photographers producing continuous-tone prints on paper. On the other hand, in photo-mechanical reproduction where colour prints are eventually produced on a mass scale, such a grey key (black printer) helps to produce a good scale of greys even when using unsuitable inks or second-quality printing and adds "punch" to the reproduction. This "punch" is often obtained at the expense of the impression of naturalness in the colour rendering.

The fourth grey-printer negative can also be made by exposing through each of the three tri-colour filters in turn on the same emulsion. The exposure through each filter should be one-third the time that would be necessary to obtain an image of normal density. The resulting negative is intended to

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Finding Filter Factors

If all the negatives are to be taken under standard lighting conditions, the filter factors, or at least their ratios, can be found with fair accuracy from tests made to determine development times (see page 257). If a grey scale is included in the picture its appearance in the three negatives will always give some idea of what alteration is needed in the filter ratios to balance the negatives.

By taking a no-filter negative in addition to the normal three negatives the actual filter factors can be found, provided that the gamma to which the negatives have been developed is known or the grey-scale reflection densities are calibrated (Fig. 67).

This is the procedure. After processing the four negatives, measure the densities of the same two steps in each grey scale. The steps selected for measurement should have densities which are known to lie on the straight-line portion of the characteristic curve. Suppose the densities are:

	Red filter	*Green filter*	*Blue filter*	*No filter*
1st Step	0·5	0·58	0·4	0·6
2nd Step	0·8	0·88	0·7	0·9

Here the density of the first and second steps differs by the same amount (0·3) in each negative. This shows that the contrast of all four negatives is equal. The actual difference in density between each of the filter negatives and the no-filter negative is 0·1, 0·02 and 0·2. With correct filter factors all negatives would

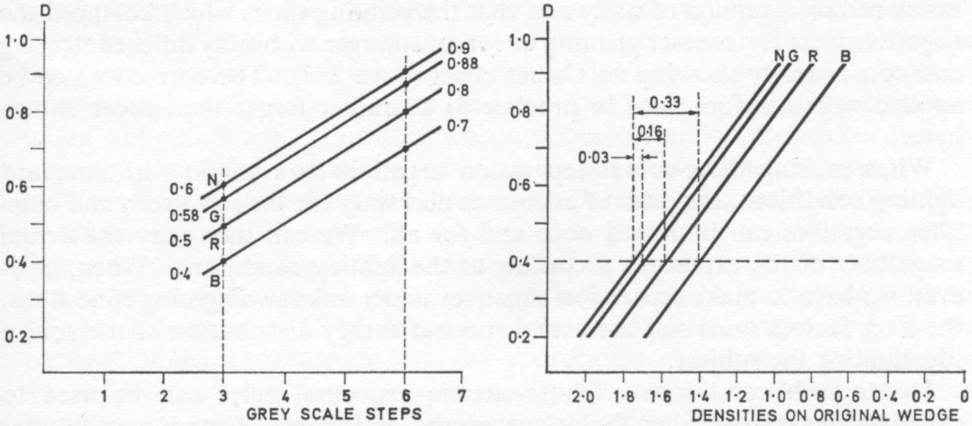

Fig. 67 Determining filter factors. First the grey scale steps on the four negatives—exposed without a filter (N) and through a red (R), green (G) and blue (B) filter respectively—are measured to plot characteristic curves (*left*). Measure the slope of the curves (they should all be equal) and multiply the filter factors originally used by the density differences, divided by the gamma. If a calibrated step wedge is available (*right*) the negative densities can be plotted directly against the original wedge densities. The horizontal displacement of the curves gives direct correction factors in terms of log exposure. For example in this case the required correction factor for the blue filter negative would be antilog 0·33 = 2·14. (This is the factor by which the blue filter factor already used for the tests must be further multiplied. Thus with an original blue factor of 8× the corrected factor would be 17×.)

have the same density. In general (as seen from the properties of a characteristic curve) a density difference of *D* corresponds to a difference in log exposure of *D*/gamma. Hence the filter factors must be adjusted by multiplying them by the anti-log of *D*/gamma, if the density was less than that of the no-filter negative. If the density was greater, divide the filter factor by the antilog of *D*/gamma. In the above example with a gamma of 0·6 a blue filter factor of say 10 becomes 10 × anti-log 0·2/0·6 = 21·5.

If the grey scale was calibrated or the tests made with a step-wedge in front of the negatives (page 284), the characteristic curves for each of the four negatives can be plotted as described on page 290. The difference in log exposure between any negative and the no-filter negative is represented by the horizontal displacement between the two curves.

In practice the corrections which should be made to the filter factors can often be estimated quite well from the separation-negative printing times, which must, of course, balance the grey scales. For example:

	Red filter negative	*Green filter negative*	*Blue filter negative*
Printing times to balance grey scale .	60	80	120
Filter factors used	3	8	9
Corrected filter factors	$\frac{3 \times 80}{60} = 4$	8	$\frac{9 \times 80}{120} = 6$

In this calculation it has been assumed that the separation negatives were developed to a gamma of unity and that the printing times which balanced the negatives were for contact printing or for an enlarger with fully diffused lighting and consequently showing no Callier effect (page 287). The corrections to be applied will therefore tend in practice to be rather larger than those shown here.

When making three-colour separation negatives in a studio with standard lighting conditions, the ratio of exposures necessary for the red, green and blue-filter negatives can be found once and for all. We can then vary the actual magnitude of the exposures according to the lighting conditions. When, however, we have to make separation negatives under unknown lighting conditions, the filter factors must suit the actual spectral energy distribution of the source illuminating the subject.

Under such conditions a photo-electric exposure meter can be used to calculate the relative filter factors necessary, as follows. Determine the filter factors for the negative material first for, say, daylight illumination. These might be, red 3, green 9, and blue 4. The filter factors of the photo cell to the same three filters are next measured in the same light. They may turn out to be, for example, red 1·5, green 2·6 and blue 4·2. Now try a similar measurement under different light conditions, and check the filter factors for the photo cell (i.e. ratio of the reading with and without filter). If these factors are say, red

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6·0, green 7·8 and blue 9·2, the relative filter factors for the negative material will be:

$$\text{Red} = \frac{3 \times 6}{1{\cdot}5} = 12$$

$$\text{Green} = \frac{9 \times 7{\cdot}8}{2{\cdot}6} = 27$$

$$\text{Blue} = \frac{4 \times 9{\cdot}2}{4{\cdot}2} = 8$$

Separation Negatives from Colour Transparencies

It is easier to make a faithful assembly colour print when separation negatives are taken direct from the subject than when they are obtained from a colour transparency. Even for photo-mechanical reproduction (except of paintings and similar flat originals) it is, however, rare nowadays to work from direct separation negatives. The majority of originals to be reproduced are colour transparencies (or colour prints) which are much easier to produce with a wide variety of amateur and professional cameras.

The difficulties in working from a subtractive transparency are due mainly to the deviation of the dyes in the transparency from the theoretical requirements (page 303) and to the great brightness range of a typical transparency (page 297). The colour rendering in the transparency is already somewhat inaccurate; this is further falsified by similar dye imperfections of the printing material. The colour rendering of the latter thus tends to be an approximation of an approximation. For this reason some correction technique such as masking is usually essential for maximum accuracy of colour rendering.

The principles of masking and the procedures for making masks are described in detail on page 296 onwards. As applied to preparing separation negatives from transparencies, masking essentially involves making from the transparency one or more low-contrast negatives and binding these in register with the original transparency. The densities of the mask, being negative, lower the contrast of the transparency and—by appropriate changing of masks during the different filter exposures—also modify the colour of the reproduction. What we are concerned with at the moment therefore is that in making separation negatives we are usually working with a sandwich of the transparency and a mask, and printing this combination on to the negative material.

It is, however, possible to produce acceptable results without such correction with a low-contrast subject where only one or two colours need to be accurately reproduced. A low subject contrast therefore always helps. In addition, the ideal transparency for making a colour print should be made slightly darker than would be considered ideal for projection, by underexposing it by about half a stop. (This increases colour saturation and highlight contrast.)

Although it is possible to correct faulty colour balance in a transparency during subsequent printing operations, this adds to the difficulties. Errors in the rendering of individual colours—as distinct from colour balance—are dealt with either by manual retouching of the negatives (page 261) or by masking.

When making separation negatives from transparencies it is again desirable to include a grey scale (and—if possible—a standard colour scale) for checking the contrast of the negatives (page 237). Transparency scales of this kind are supplied by several manufacturers of sensitive materials in the form of small strips which can be taped to one edge of the transparency.

Contact Printing and Enlarging

The simplest way of making the three separation negatives from a transparency is by contact printing, with a red, green and blue filter respectively in front of the exposing light. Although this works well with the larger transparency sizes, imperfect contact between the negative and the transparency during printing may cause a slight loss of definition. This is usually made worse by the thickness of the tape which is used to hold the transparency in register with the mask (where used) or on to the backing plate. In sizes under quarter-plate or 9 × 12 cm. it is worth sticking the edges of the transparency down on to the mask with rubber solution.

Contact printing is not really satisfactory for 35 mm. transparencies unless a vacuum frame is used, and it is better to make the separations by enlargement.

The transparency (with its mask) is put in the negative carrier of the enlarger and the filters placed in turn over the enlarger lens. The separation negatives are exposed on the enlarger baseboard. For maximum resolution the image size should be at least 4 × 5 inches, but a smaller size may have to be used in order to fit into the enlarger when making the colour prints.

The enlarger must be well designed and rigid. Only image-forming light must be allowed to reach the sensitive material. The carrier should hold the transparency firmly and allow it to be taken out, registered with another mask, and put back without in any way altering the focus or the size of the projected image. The enlarger lens has to bring the three images to the same focus, so good colour correction is important. Ideally an apochromatic lens should be used.

Another way of making the separation negatives is to light the transparency evenly from behind and to photograph it three times with a camera through the tri-colour filters. The method is useful for making reduced separation negatives

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Narrow-cut Separation Filters

When making separation negatives from transparencies it is preferable to use special narrow-cut tri-colour filters. This is because the colours of a transparency are combinations of three dyes. Although the colours appear visually the same as those of the original scene, they are in fact physically not identical, for they record the scene in terms of three primary colours. The object is to obtain separate records each in terms of one of these primaries—which would be simple if we could separate the layers of the transparencies physically. Since we cannot do this, we have to rely on the differences in the spectral transmissions of the cyan, magenta and yellow images.

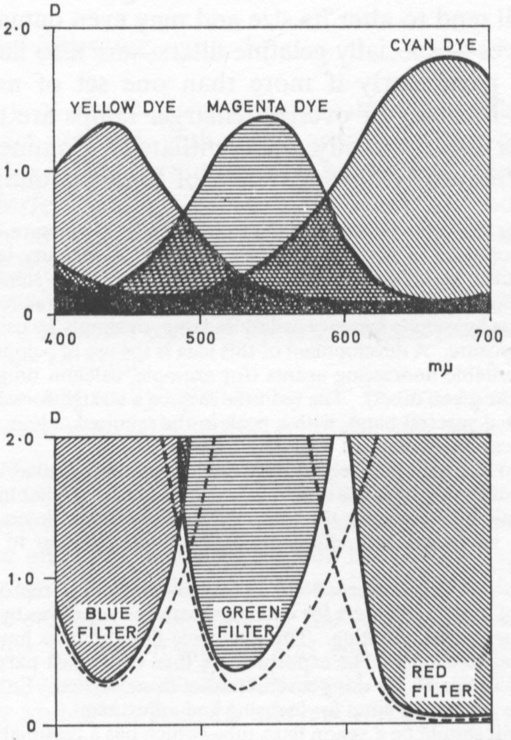

Fig. 68 Spectral densities of dyes and analysis filters. The density curves of dyes forming the transparency rise over one-third of the spectral range, but each dye absorbs an appreciable amount of the other two colours. For good separation each analysis filter should therefore have a narrow band with its peak at the maximum transmission of the colour record, consistent with the minimum possible transmission of the other two records of the transparency. The solid curves (*shaded*) in the lower graph correspond to narrow-cut filters; the dotted curves to typical standard tri-colour filters. (After *Colour Separation Negatives* by Philip Jenkins; London, 1957.)

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As the transmissions of these dyes overlap (Fig. 68) no set of filters can separate the images completely. By using narrow-cut filters we can avoid some of the overlap. As the dyes employed are not the same in all makes of transparency, the overlaps differ and special sets of filters are often recommended by the film manufacturer to fit his products. Such analysis filters result in slightly higher saturation than a standard set.

If the separation negatives are made by enlargement and the filters used in front of the lens, they must be of the same optical quality recommended for taking direct separations with a camera (page 234). When the negatives (or masks) are contact-printed, the filters can conveniently be enclosed between two sheets of thin Perspex of suitable size to fit into the lamphouse in the enlarger or into a frame in front of the safe light (where the latter is used for contact printing.)

Balancing Filter Factors

As with direct-separation negatives, filter factors depend on the filters used, the spectral sensitivities of the negative material and the colour quality of the light source. It is inconvenient to have widely different filter factors, and this becomes more serious with longer exposures because of increasing liability to reciprocity failure. Its effect is to separate the filter factors for correct exposure still further, and calculations have to be made to determine the amount in each case.

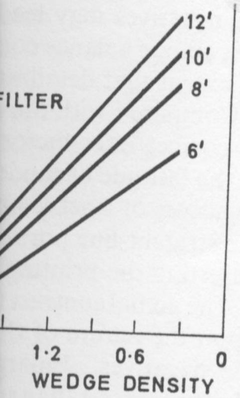
It is therefore worth while balancing the filter factors to bring them closer. For contact printing this may be done:

(*a*) By altering the size of the aperture. The amount of light reaching the printing frame depends on the area of the aperture in the light source (provided the latter is larger than the filter). A 4-inch-diameter aperture will then give 4 times as much light as one of 2 inches diameter.

(*b*) By adding a neutral density to the filters which have the smallest filter factor. Thus if the exposure times to balance the separation negatives are red = 5, green = 18, blue = 100 seconds, neutral-density filters with densities of 1·3 (opacity 20) and 0·76 (opactity 5·6) would be needed for the red and green filters respectively.

Where separation negatives are made by enlargement, only method (*b*) is practical. The simplest method with an enlarger is to vary the aperture of the enlarging lens.

If initial tests, as described on page 239, are made to find the filter factors, the areas of filters or the neutral densities needed to balance the exposures can be calculated with fair accuracy.



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The simplest way out of this difficulty is to use special colour-separation emulsions, marketed by a few manufacturers, and designed to yield identical contrast for all three separation negatives at a given development time. Failing such materials, the development times can be found from manufacturers' published gamma-time curves or development recommendations, where they are available for three-filter colours. Decide on the gamma to be used, and draw a horizontal line across the curves at the gamma value. Where this horizontal line cuts the three curves, verticals dropped down to the horizontal time scale show the actual development times (page 256). Published time-gamma curves and development times apply to specific developers which must be used.

Where no published figures are available, separate tests are necessary, and involve making a series of exposures through a step-wedge on to, say, a dozen films or plates to be used for separation. Four exposures are made through the red filter, four through the green filter, and four through the blue filter. Then negatives are developed in sets of three for 6, 8, 10 and 12 minutes respectively in the chosen developer. Next measure the densities of each of the steps in the wedge on all the red-filter negatives, and plot a characteristic curve for each red-filter negative on a common graph. Plot similar sets of curves for the green-filter and blue-filter negatives. Finally, measure the gamma of each curve. The simplest way of doing that is to mark off a wedge density range of 1·0 along the horizontal axis of the graph, making sure that this range corresponds with the straight-light portion of the curve. Then measure the corresponding negative density range; this gives a direct figure for the gamma. A gamma-time curve plotted from these figures for each set of negatives then yields the required development times for uniform gamma (Fig. 71).

The number of separate negatives can be reduced from twelve to four if the three-filter records are combined on one plate—for example by attaching three strips of red, green and blue filter material to the front of the step-wedge, running along its length.

If possible, expose the test negative directly in contact with the step-wedge to eliminate errors due to lens flare in the optical system of an enlarger. However, if all three negatives are exposed under the same conditions, the result will still give the development times required to balance the contrast of the negatives. Only the actual gamma values may not be correct.

Effect of Contrast on Filter Factors

If the development time of one of the negatives has to be increased to achieve uniformity of contrast in the set, it will considerably increase the density of the middle tones of the negative and also slightly increase its speed. This will, in turn, affect the filter factors (page 235). We may, however, correct the filter factors for the old development times and make allowances for the changes we are going to make.

This requires exposing a set of separation negatives to a step-wedge through a red, green, and blue filter respectively—as for the test used to establish correct development times. In addition, we also need a negative exposed without a filter. The exposure times for all negatives must be adjusted according to the filter factor.

After processing select the corresponding wedge step on each negative, and measure its density. Use a step near the middle of the range, with a density of around 0·5 or 0·6 on the no-filter negative. Note down the densities of the corresponding step on each negative, for example, in the form below:

	Red filter negative	*Green filter negative*	*Blue filter negative*	*No filter*
Step density .	0·5	0·58	0·4	0·6

The differences in density between each of the filter negatives and the no-filter negative are 0·1, 0·02 and 0·2 respectively.

Now if the factors had been correct, all negatives would have the same density. From the characteristic curve the density difference D corresponds to a difference in the log exposure of D/gamma. Hence the filter factors must be adjusted by multiplying them by the antilog of D/gamma, if the density on the filter negative is less than that of the no-filter negative. If the density of the corresponding step on one of the filter negatives is greater, divide the filter factor by the antilog of D/gamma. In the above example, with a gamma of 0·6, a blue-filter factor of, say, 10 becomes 10 × antilog (0·2/0·6) = 21·5.

If the gamma of the green-filter and red-filter negatives is 0·8, the blue-filter negative will need extra development to increase its gamma from 0·6 to 0·8. That also increases its effective density. To make allowance for both variables multiply the *old* filter factor by the antilog of

$$(d_1/\gamma_1 - d_2/\gamma_2)$$

where d_1 is the density of the negative to be matched, d_2 the density of the negative requiring correction, γ_1 the negative gamma to be matched, and γ_2 the gamma of the negative requiring correction.

The filter factor for the blue-filter negative would therefore be 10 × antilog (0·6/0·8 − 0·4/0·6) = 10 × 1·2 = 12.

After making these calculations, a new test using the modified filter factors and development times should produce a result which is near enough in practice.

For most purposes it is the ratio between the filter factors and not their actual values which matter. We can save time and film by leaving out the no-filter negative and calculating the filter factors taking the green (which usually varies least) as the criterion.

Developers and Development Methods

The ideal developer for separation negatives yields the longest possible straight-line characteristic curve for the emulsion, with a slow rate of change of contrast near the end of development, so that timing is not too critical. It is also an advantage if the developer can be diluted, so that a reasonably long development time still yields the low contrast needed for masks.

Most manufacturer-recommended developers are straightforward Metol-hydroquinone formulae. It is best to avoid special fine-grain developers with a high sulphite concentration, as they tend to distort the characteristic curve and reduce highlight contrast. Maximum-energy developers are also liable to give unrepeatable results. A stop bath (such as 2 per cent acetic acid) is desirable immediately after development to terminate the process at a predictable point.

For uniform development three conditions are important:

(*a*) Frequent agitation, to renew the developer in contact with the negative surface at regular intervals. As the degree of agitation affects the development rate, development times must be based on a standard agitation.

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